Special Well Construction and Abandonment Procedures

For

Yuma Marine Corps Air Station CERCLA Site

October 2002

Arizona Department of Water Resources

WQARF Support Unit – Hydrology Division

ARIZONA DEPARTMENT OF WATER RESOURCES

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Acronyms

A.A.C	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
A.R.S.	Arizona Revised Statute
AS/SVE	Air Sparge/Soil Vapor Extraction
bls	below land surface
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
DCE	1,1-Dichloroethylene
EPA	Environmental Protection Agency
ft	feet
ft/yr	feet per year
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
msl	mean sea level
NOI	Notice of Intent
NPL	National Priority List
PCE	Tetrachloroethylene
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
TCE	Trichloroethylene
TDS	Total Dissolved Solids
ug/L	micrograms per liter
WQARF	Water Quality Assurance Revolving Fund
YMCAS	Yuma Marine Corps Air Station

Introduction

The intent of this document is to provide guidance to well owners and drillers in constructing wells or performing abandonments to protect ground water in the area of known or anticipated ground water contamination that is located in, or within close proximity of the Yuma Marine Corps Air Station (YMCAS). This area was selected for special well construction and abandonment procedures due to existing ground water contamination conditions at the site and in recognition of the numerous Notices of Intent (NOI) to drill domestic wells near YMCAS (14 in the past two years) and the potential for vertical cross-contamination to occur across aquifer boundaries.

The Arizona Department of Water Resources (ADWR) is required by statute to adopt rules establishing construction standards for wells, including the abandonment of existing wells. A.R.S. § 45-594(A). The Department adopted such rules effective March 5, 1984, and amended the rules effective June 18, 1990. The well construction and abandonment rule is set forth in Arizona Administrative Code (A.A.C.) (R12-15-801 through R12-15-852), *Statutes and Rules Governing Minimum Well Construction Standards,* (January 3, 2000).

Section R-12-15-812B of the A.A.C. describes special aquifer conditions, specifically for mineralized or polluted water. The rule states that "In all water-bearing geologic units containing mineralized or polluted water as indicated by available data, the borehole shall be cased and grouted so that contamination of the overlying or underlying ground water units will not occur." Although the rule states the objective, it does not specify the methods or materials for either well drilling or abandonment. A Substantive Policy Statement, *Well Abandonment Handbook*, issued by ADWR and dated September 20, 2001, addresses a broad range of abandonment situations including areas with ground water quality contamination; however site-specific guidance on aquifer boundaries and known areas of ground water contamination is not given. The design, procedures, and materials used during the drilling, modification or abandonment of a well must prevent vertical cross-contamination between an aquifer or aquifers layers and ensure the seal integrity.

A.R.S. § 45-605 (E) requires that ADWR develop a review process for all applications to drill, deepen, or modify a well located in an area of known or anticipated ground water contamination to insure that proposed wells are designed in a manner to prevent vertical-cross contamination.

Specific well drilling and well abandonment requirements cited in this document apply in addition to other ADWR statutes, rules, and substantive policy statements that regulate the drilling and abandonment of wells:
Statutes and Rules Governing Minimum Well Construction Standards (August 22, 1997), and Substantive Policy Statement Well Abandonment Handbook (September 20, 2001).

Disclaimer:
These well construction and abandonment procedures are meant to serve as guidelines for applicants seeking to obtain a drill card. Each NOI to Drill or NOI to Abandon a well within the specific area of concern will still be examined on an individual basis. Changes in contaminant concentrations, ground water flow direction, or other factors may necessitate modifications to these standards.

Location and Site History

The Marine Corps Air Station at Yuma (YMCAS) is located approximately one mile southeast of the city of Yuma, Arizona and approximately 5 miles south of the Colorado River (Figure 1). The YMCAS occupies approximately 3,000 acres of desert scrub on an elevated alluvial terrace known as Yuma Mesa and is located in Township 9 South, Range 23 West. The base is situated at the northern end of Yuma Mesa, a relatively flat topographic feature that rises approximately 65 feet (ft) above the surrounding valley floor. Elevations on the mesa range between 140 to 290 ft above mean sea level (msl). The most distinctive geographic feature at the site is a 90-ft high bedrock outcrop known as Radar Hill.

The site is primarily industrial, and has been used by military and civilian aircraft and their support operations since 1928 (Jacobs 1996). Various airport facilities (runways, aprons, and taxiways), landfill and disposal areas, fire-training areas, roads, miscellaneous buildings, and residential areas are within the base boundaries. Environmental assessment studies conducted in 1985 found chlorinated solvents in ground water; the site was listed on the U.S. Environmental Protection Agency's (EPA) National Priority List (NPL) in February 1990 and is classified as a "Comprehensive Environmental Response, Compensation and Liability Act" (CERCLA) remedial site.

Site Geology

The broad, deep alluvial valleys of the Yuma area are typical of the Basin and Range lowlands province that covers most of southern Arizona. This physiographic province is characterized by elongated northwest – southeast trending fault-block mountain ranges. The Algodones Fault, a southeast to northwest trending fracture, crosses the southern end of the mesa, approximately four miles south of the base. There has been no recent evidence of soil displacement, but the area is considered to be an active seismic unit (Stearns et al., 1985). The Gila Mountain and Laguna Mountain ranges define the northern edge of the basin that extends far south into Mexico (Figure 1). Alluvial fan deposits from the surrounding mountains and several millions of years of deposition from the ancestral Colorado River have filled the Yuma Valley with thousands of feet of alluvium (Figure 2).

The following description generalizes the YMCAS area geology in descending order of deposition (Table 1). A thin veneer of wind-blown dune sand and silt comprise the land surface of Yuma Mesa; underlying the surficial deposits, the mesa is composed of unconsolidated, fine to medium sands with interbedded silts and sandy clays deposited by the ancient Colorado and Gila Rivers. These Holocene/Pleistocene Age deposits extend from the surface of the mesa to the valley floor (Jacobs, 1996). Clay lenses, interspersed within these unconsolidated sands, are laterally discontinuous and range from a few inches to as much as 10 ft thick.

A continuous fine to coarse gravel layer 0 to 100 ft thick underlies the fine to medium sands of the ancestral river systems. This prominent stratum is near sea level, approximately 200 ft beneath the YMCAS site, and extends laterally throughout the basin (Olmsted et al., 1973).

Pleistocene alluvial and fluvial sand deposits that are hundreds of feet in thickness underlie the coarse gravel deposits that were deposited by the ancestral Colorado and Gila Rivers. Next in the sequence are Pliocene-age fluvial and deltaic sediments composed of unconsolidated and interbedded sands, marine silts and clays. Semi-consolidated to consolidated units of marine silts and clays of the Lower Bouse Formation overlie Miocene sandstone, siltstone, and shale. Mesozoic granitic gneiss, estimated at depths of 2,000 ft below land surface (bls), underlie the Miocene sandstones (Jacobs, 1998).

Radar Hill is believed to be an outcrop of the deep basement rocks, exposed as part of a buried, low-lying ridge. Four similar outcrops exist in the Yuma area; the grouping is known as the Yuma Hills and is part of a north-northwest trending bedrock exposure (Figure 2).

Site Hydrogeology

The Yuma aquifer system is generally classified into the upper transmissive zone and the lower transmissive zone. The upper transmissive zone consists of three units: the upper fine-grained unit which includes significant clay layers, the coarse gravel unit, and the top of the wedge unit. The bottom of the wedge unit and bedrock make up the lower transmissive zone. Saturated sediments in the upper transmissive zone act as a single unconfined to semi-confined unit. Water levels in all units tend to equilibrate quickly, indicating high transmissivity and high vertical hydraulic interconnections. (ADWR, 1993). This guidance document focuses only on the aquifer characteristics of the upper transmissive zone as most wells in the area are screened within this zone.

The direction of regional ground water flow for the greater Yuma area is from the northwest to the southeast, except for the Yuma Mesa area. Since 1925, intensive agricultural irrigation has created a ground water mound beneath the mesa, causing ground water to mound and flow radially from the center of the mound (Bechtel, 2000). The center of the mound is located to the east and south of the YMCAS site, the direction of flow beneath the YMCAS site is from southeast to northwest (Jacobs 1997).

Depth to water across the site ranges from 40 to 64 ft bls, at approximate elevations ranging between 140 to172 ft above msl (Arizona Department of Environmental Quality (ADEQ), 2001). Water levels have remained relatively stable since the site investigation began in the 1980s. Estimates of the horizontal hydraulic gradient vary for the area, however most recent reports cite values of 0.002 to 0.003 (ADEQ, 2001). Estimates of vertical hydraulic gradient from a modeling report cite 0.008 upward near the western site boundary, and 0.005 downward near the eastern site boundary (Jacobs, 1999). Estimates of horizontal ground water velocity also vary, depending on selected values of hydraulic conductivity, horizontal hydraulic gradient, and porosity. Gross estimates of horizontal ground water velocity range from 150 to 250 feet/year (ft/yr). These estimates were calculated using hydraulic conductivity estimates of 65 to 110 ft/day.

Previous Investigations

Many investigators, most prominently Olmsted (1973), Stearns (1985), and Jacobs (1996) have defined aquifer boundaries for the YMCAS site. These previous investigations were reviewed for this report; each study describes the same aquifer units: the upper fine-grained unit with discontinuous clay lenses, the coarse gravel unit and top of the wedge unit, and the consolidated units below the wedge unit. ADEQ and the EPA both oversee the remediation of the site and have recognized these same hydrogeologic units. Descriptions of the units are provided in the YMCAS initial site assessment, the Remedial Investigation and Feasibility Study (RI/FS), and record of decision (ROD).

These hydrogeologic units were compared to units described in ADWR's regional model of the Yuma area (ADWR, 1993). The units were essentially comparable except that the ADWR model describes a discrete clay layer, "Clay B", within the upper fine-grained unit.

Conceptual models of previous investigations were compared by constructing numerous cross-sections utilizing 33 geologist logs and over 100 driller logs. Upon review of available data, it was determined that the 1993 regional ADWR model layers developed for the Yuma regional ground water model closely matched site-specific conditions and therefore are sufficient for reference at the YMCAS (Figure 3).

Hydrogeologic Units

Based on the review of the available site-specific information, three hydrogeologic units have been identified that must be protected from potential vertical cross-contamination through proper well construction and well abandonment designs. Hydrogeologic units defined for the YMCAS site are: the upper fine-grained unit, the coarse gravel unit, and the top of the wedge unit (Table 1).

Upper Fine-Grained Unit

The total thickness of the upper fine-grained unit is approximately 180 to 200 feet thick at the site. This hydrogeologic unit correlates with the Quaternary eolian deposits and the unconsolidated, inter-bedded sands, silts and sandy clays of the ancient Colorado and Gila Rivers. Many shallow wells on the Yuma Mesa are screened in this unit; water quality is variable due to the large volume of irrigation recharge (Jacobs, 1998). The depth to water beneath the YMCAS is between 40 to 80 ft (Jacobs, 1998). Ground water in the upper fine-grained unit is generally characterized as 'slightly saline,' with total dissolved solids (TDS) of 1,000 to 3,000 mg/L (ADEQ, 1998).

The upper fine-grained unit contains numerous, mostly discontinuous, clay lenses. A poorly defined but areally extensive clay deposit known as "Clay B" lies within the upper fine-grained unit (ADWR, 1993). This layer is between 10 and 15 feet in thickness and composed of clay and silty clay, with small amounts of fine sand and scattered pebbles. The clay layer probably impedes vertical flow from the upper fine-grained unit to the underlying coarse gravel unit layer (Stearns et al., 1985).

Isopach maps from the Yuma ground water model (ADWR, 1993) show the following stratigraphy at the YCMAS site: 50 to 90 ft of sediments above Clay B, 0 to 15 ft thickness of Clay B and 60 to 120 ft of sediments below Clay B. Transmissivity values for the upper fine-grained unit range between 1,600 to 10,000 ft^2/day with horizontal hydraulic conductivity values estimated at 50 to 500 ft/day (ADWR, 1993). Vertical hydraulic conductivity values of 0.0003 ft/day were determined from laboratory permeameter tests (Jacobs, 1999). Harshbarger (1971) and Jacobs (1990) estimated a storage coefficient of 0.001. Specific yield estimates range from 0.18 to 0.35 (Olmsted and others, 1973).

Coarse Gravel Unit

The primary regional aquifer is the coarse gravel unit that underlies the upper fine-grained unit. This strata varies in thickness from 0 to 100 ft throughout the Yuma area, maximum thickness occurs near the center of the valley and thins toward the mountain fronts. The fluvial and deltaic gravel sequence composed of fine to coarse gravel with cobbles up to 10 inches in diameter below the YMCAS site is believed to be between 20 and 50 ft thick. This is the most permeable unit in the sequence. Depth to this layer from the mesa surface is approximately 180 ft (ADWR, 1993). Ground water in the coarse gravel unit is generally characterized as 'slightly saline,' with TDS of 1,000 to 3,000 mg/L (ADEQ, 1998).

Wedge Unit

The deepest, thickest, and oldest unit of the Yuma aquifer system is known as the wedge unit and is composed of ancestral Colorado River fluvial and deltaic alluvial deposits, a marine sedimentary sequence (Bouse Formation), and siltstone and sandstone deposits (Stearns et al., 1985). Water in this unit is generally of better quality than in the overlying units. Transmissivity values for the coarse gravel and upper wedge unit range between 9,000-240,000 ft^2/day with horizontal hydraulic conductivity (average maximum) estimated at less than 1,300 ft/day (ADWR, 1993). Harshbarger (1971) estimated vertical hydraulic conductivity at approximately 0.10 ft/day. A storage coefficient of 0.001 was estimated from Harshbarger (1971) and Jacobs (1990). Specific yield estimates range from 0.18 to 0.35 (Olmsted and others, 1973).

This unit is up to 2,000 ft thick and underlain by crystalline bedrock (Jacobs, 1998). This bedrock is the same rock type that occurs as the surface outcrops known as the Yuma Hills. Radar Hill, the bedrock outcrop within the site (coarse-grained granite and gneiss), is slightly weathered, but lacking well-defined joints and fractures that could contribute significant permeability (Olmsted et al., 1973).

Nature and Extent of Ground Water Contamination

Various chlorinated hydrocarbon solvents associated with the operation and maintenance of aircraft have been detected in the soil and ground water at the site. The primary contaminants of concern are TCE (trichloroethene), PCE (tetrachloroethene), and 1,1-DCE (1,1-dichloroethene).

Monitoring wells were installed and periodic monitoring has been ongoing since the mid-1980s. Initial analyte results indicated solvent levels in excess of the state's drinking water standards for TCE, PCE, and DCE. These exceedances have decreased in all of the areas of concern and Remedial Actions have been instituted for those areas with contaminants above the Maximum Contaminant Level (MCL) (Bechtel, 2000). MCL levels for TCE, PCE, and 1,1-DCE are 5 ug/L, 5 ug/L, and 7 ug/L respectively. These contaminants have been found mostly in the upper fine-grained unit.

Early studies in 1980, through the Department of the Navy Installation Restoration Program, identified four contaminant plume areas that impacted ground water. These four areas of concern were designated Areas 1, 2, 3, and 6 (Figure 4). Areas 4 and 5 were sites with contaminated soils and no impact to ground water (Jacobs, 2000).

The Area 1 plume is approximately 60 acres in lateral extent and is the largest contaminant plume at the site. Ground water in the Area 1 plume is contaminated with TCE, PCE, and 1,1 DCE from a source area near Building 230 (Figure 4). The plume extends from the source at the eastern end of the base to just beyond the base boundary at the west. This plume is restricted to the upper portion of the upper fine-grained unit, but appears to extend slightly downward at the western edge. Initial concentrations (1995) near the 'hot spot' area at the source were 450 ug/L TCE, 16 ug/L PCE, and 158 ug/L 1,1-DCE. December 2001 sampling results show a high of 130 ug/L TCE and 38 ug/L 1,1 DCE for two wells. Most of the remaining sampled wells at the 'hot spot' are slightly above or below the Primary Maximum Contaminant Level (MCL).

The Area 2 plume is approximately 4 acres in extent and consists primarily of ground water that is contaminated with1,1 DCE probably associated with a leach field near a jet engine testing cell. The maximum reported initial concentration (1995) in this area was 210 ug/L. Sampling results from January 2002 showed a maximum 1,1 DCE concentration of 4.1 ug/L. PCE and TCE were not contaminants of concern at this area.

The Area 3 plume is approximately 10 acres in extent and contaminated primarily with TCE and 1,1 DCE from activities associated with an unlined fire-training pit. Initial maximum concentrations (1995) were 13 ug/L and 10 ug/L for TCE and 1,1 DCE, respectively. December 2001 sampling results indicated non-detects for both of these compounds.

The Area 6 plume is very small (less than 1 acre); contaminated primarily with PCE from concrete fuel tanks that had been situated nearby. Initial maximum PCE concentrations (1995) were reported at 7 ug/L; the most recent sampling in December 2001 found 3.2 ug/L. TCE and 1,1-DCE were not contaminants of concern at this area.

ADEQ Remedial Actions

Area 1: An air sparge/soil vapor extraction (AS/SVE) system consisting of 15 monitoring and extraction wells and 41 air sparge wells was implemented in 1999 for the 'hot spot' of the Area 1 plume. A system of vertical recirculation wells were installed at the leading edge of the Area 1 plume (Figure 4) at the northwest corner of the YMCAS site in June 2000. Ground water flow and contaminant transport modeling and sampling will be continued throughout the next 30-40 years, the expected duration of remedial action.

Areas 2, 3, and 6: The contaminant plumes associated with these areas are considered relatively small and stable. Two small-scale AS/SVE systems were installed in Areas 2 and 3 in September 2000. Institutional controls and continued ground water monitoring have also been implemented. (ADEQ, 2001). Natural attenuation is expected to bring contaminant levels below MCLs within the next five years. Areas 3 and 6 are being considered for site closure by lead agencies. (Bechtel, 2000).

Area Requiring Special Well Construction and Abandonment Procedures

The area where special well construction and well abandonment procedures, designed to prevent vertical cross-contamination, are required is shown in Figure 5. All wells that will be drilled, modified, or abandoned within the area requiring special procedures must meet the conditions outlined below. The area requiring special well construction and abandonment procedures was defined based upon the review of the many hydrogeologic reports and maps that cover the general Yuma area and the CERCLA site specifically (ADWR, 1993, Jacobs, 1996, Olmsted et al., 1973, Stearns et al., 1985, Terra Vac, 2002). Special well construction procedures are required for the delineated area in an attempt to protect existing and future ground water users from contaminated ground water and preventing vertical cross-contamination between defined aquifer layers. The boundary was drawn based on considerations of the direction of localized ground water flow, the vertical and horizontal extent of contamination (primarily the Area 1 plume), estimates of ground water velocity, and future contaminant distribution projections provided by ADEQ-contracted ground water modeling studies.

The Navy consultants developed a 3-dimensional computer model of Areas 1, 3, and 6 using varied scenarios and timeframes (Jacobs, 1999). Projections for the migration of the largest and most contaminated plume (Area 1 plume of TCE) under a ‘No Action Scenario’ predicted that the contamination would attenuate to levels below the current MCL of 5 ug/L within 30-40 years.

Possible scenarios not simulated by modeling but that might cause changes in the direction of ground water flow and unpredicted plume migration were also considered. These include the possibility of the installation of new high volume pumping wells and/or reduction of the ground water mound that exists beneath Yuma Mesa due to decreased agricultural recharge (Olmsted, 1973). Either of these factors could cause significant changes in the direction and gradient of ground water flow at the site. The boundary defining the area of special well construction procedures was delineated to provide for a possible shift in ground water flow direction and/or plume migration direction, and is equidistant from the largest contaminated plume (Area 1).

Special Well Construction Requirements

The well design, drilling procedures, and construction materials used during the drilling or abandonment of a well must prevent vertical cross-contamination between an aquifer or aquifer layers. The following shall apply in addition to the ADWR ***Statutes and Rules Governing Minimum Well Construction Standards*** (August 22, 1997) (R12-15-80l through R12-l5-822). Section R12-15-812(B) applies specifically because this area contains mineralized and/or polluted water. The following special conditions apply to all well types and must be met for **the construction of new or modified wells** within the defined boundaries shown in Figure 5. A typical well design for wells drilled within the YMCAS area requiring special well construction is shown in Figure 6.

Aquifer boundaries defined in this document include the upper fine-grained unit, coarse gravel unit, and the wedge unit. These are described in the Hydrogeologic Units section and in Table 1.

- If the well penetrates the bottom of the upper fine-grained unit and extends into the coarse gravel unit, the annular space between the casing and borehole must be sealed 25 feet above and 25 feet below the upper fine-grained unit/coarse gravel unit contact for a total of 50 feet of seal between the defined hydrogeologic units. Depth to this contact will vary with site location, but generally, the contact occurs at 150 to 220 feet bls. The seal material must be one of the acceptable grout materials shown in Table 2 or a variance request must be submitted.

- If the coarse gravel unit is not encountered during the drilling of a well deeper than 220 ft within the special requirements area, then a 50 foot seal must be installed between the casing and borehole at a depth of 220 ft bls to 270 ft bls. The seal material must be one of the acceptable grout materials shown in Table 2 or a variance request must be submitted. For wells drilled slightly deeper than 220 ft, a variance may be requested to adjust the required seal interval.

- Casing perforations may not extend across the contact between the upper fine-grained unit and the coarse gravel unit. Similarly, wells with multiple screened intervals may not be completed in both the upper fine-grained unit and the coarse gravel unit. This is to prevent vertical cross-contamination from contaminants in the overlying upper fine-grained aquifer to the coarse gravel unit.

- As stated within the ***Statutes and Rules Governing Minimum Well Construction***, all joints shall be waterproof to prevent leakage of fluids. Threaded flush joints are preferred within areas of known ground water contamination (EPA, March 1991, p. 85). The casing material must be chemically inert with contaminants of concern within the ground water as recommended by EPA, March 1991, p.75.

- Three to five feet of fine silica sand (less than approximately 0.25-millimeter diameter) shall be placed over filter pack material when filter pack material is used.

- There must be at least 2 inches of annular space between the casing and the borehole to allow for sufficient emplacement of grout, bentonite, or filter pack materials (EPA, March 1991, p. 86).

Special Well Abandonment Requirements

The following conditions must be met for **the abandonment of existing wells** within the specified special well construction boundaries of the YMCAS site. These conditions are in addition to the Department's minimum well abandonment requirements as stated in the Arizona Administrative Code (A.A.C.) R12-15-816. Please note that most monitoring wells will not need to be videologged or re-perforated due to their relatively recent age and proper well construction.

- The well design, location, condition of the casing, and condition and depth of perforations must be known prior to abandonment.

- If this information is unavailable, the entire length of the well casing may be removed, or

- The entire length of the casing must be re-perforated from 20 feet above the highest historic water level to the total depth of the well with a minimum of 2 cuts per foot, or

- The well may be videologged and the videotape submitted to ADWR for review. The purpose of the videologging is to observe the condition and depth of perforations, the condition of the casing, any evidence of perched water, and current depth to water.

- If the video log demonstrates that the perforations are sufficiently open to allow the tremied grout mixture to flow through the perforations and out into the annular space around the casing, no additional perforations and/or casing treatments will be required. A variance may be requested if it is determined that the disturbance of the casing and/or gravel packed units would negatively influence the sealing of the well.

- After the casing has been removed or re-perforated or a variance granted, the well must be filled completely with an acceptable grout material which includes neat cement, cement-bentonite grout, high-solids bentonite grout (granular or powder mixtures) with a minimum of 25% solids by weight, or high-solids bentonite chips and pellets. See Table 2 for specific materials and mixing ratios.

- Grout materials must be emplaced under sufficient pressure to fill all voids, including all annular space(s), and displace water from the well. A tremie pipe must be used to emplace the grout from the bottom of the well to the top. The end of the tremie pipe must remain in close proximity to the rising grout surface as the grout is pumped into the well.

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Table 1 Description of hydrogeologic units in the YMCAS area

Depositional Environment	Era	Period	Age	Approximate Thickness (ft)	Description of Material	Model Layer (ADWR)	Aquifer Classification	Transmissivity Zone
Eolian	Cenozoic	Quaternary	Holocene	Surficial	Loess (wind blown sand) deposits	#1	Upper Fine-Grained Zone	Upper Transmissive Zone
Ancestral alluvial, fluvial and deltaic sediments deposited by the Colorado and Gila Rivers			Pleistocene	50-100	Unconsolidated fine-medium fluvial/ alluvial sands			
				0-15	Laterally extensive but discontinuous silt and clay layers (Clay B)	#2		
				60-120	Unconsolidated fine-medium fluvial/alluvial sands	#3		
				0-100	Gravel deposits (near sea level), fine to coarse gravel with cobbles	#4	Coarse Gravel Zone	
				300	Alluvial/fluvial sands		Top of Wedge Zone	
		Tertiary	Pliocene	300	Unconsolidated and interbedded fluvial sands and gravels, marine silts and clays			Lower Transmissive Zone
Marine					Bouse Formation - semi-consolidated to completely consolidated marine silts and clay		Bottom of Wedge Zone	
Non-marine			Miocene		Sandstone, siltstone, and claystone			
Igneous/Metamorphic	Mesozoic				Granitic gneiss, crystalline bedrock			

[Modified after Olmsted et al, 1973 and ADWR, 1993]

Table 2. Acceptable annular seal material mixtures

Specific Material	Solids	Water	Permeability (cm/sec)
Neat Cement or Neat Cement Grout	One sack of cement (94 lb.)	Not more than six (6) gallons water	10^{-5} to 10^{-7}
Cement-Bentonite Grout	One sack of cement (94 lb.) & 3-5 lbs. Bentonite	Not more than six and one half (6.5) gallons water	10^{-5} to 10^{-11}
High Solids Bentonite Grout with a minimum 25% solids by weight.	50 lbs. dry bentonite powder	Eighteen (18) gallons water	10^{-8} to 10^{-9}
High Solids Bentonite Grout with a minimum 25% solids by weight.	150 lbs. dry granular bentonite & 1 quart polymer (granular mixture)	Fifty-four (54) gallons water	10^{-8} to 10^{-9}
High-Solids Bentonite Chips and Pellets	NA	NA	---

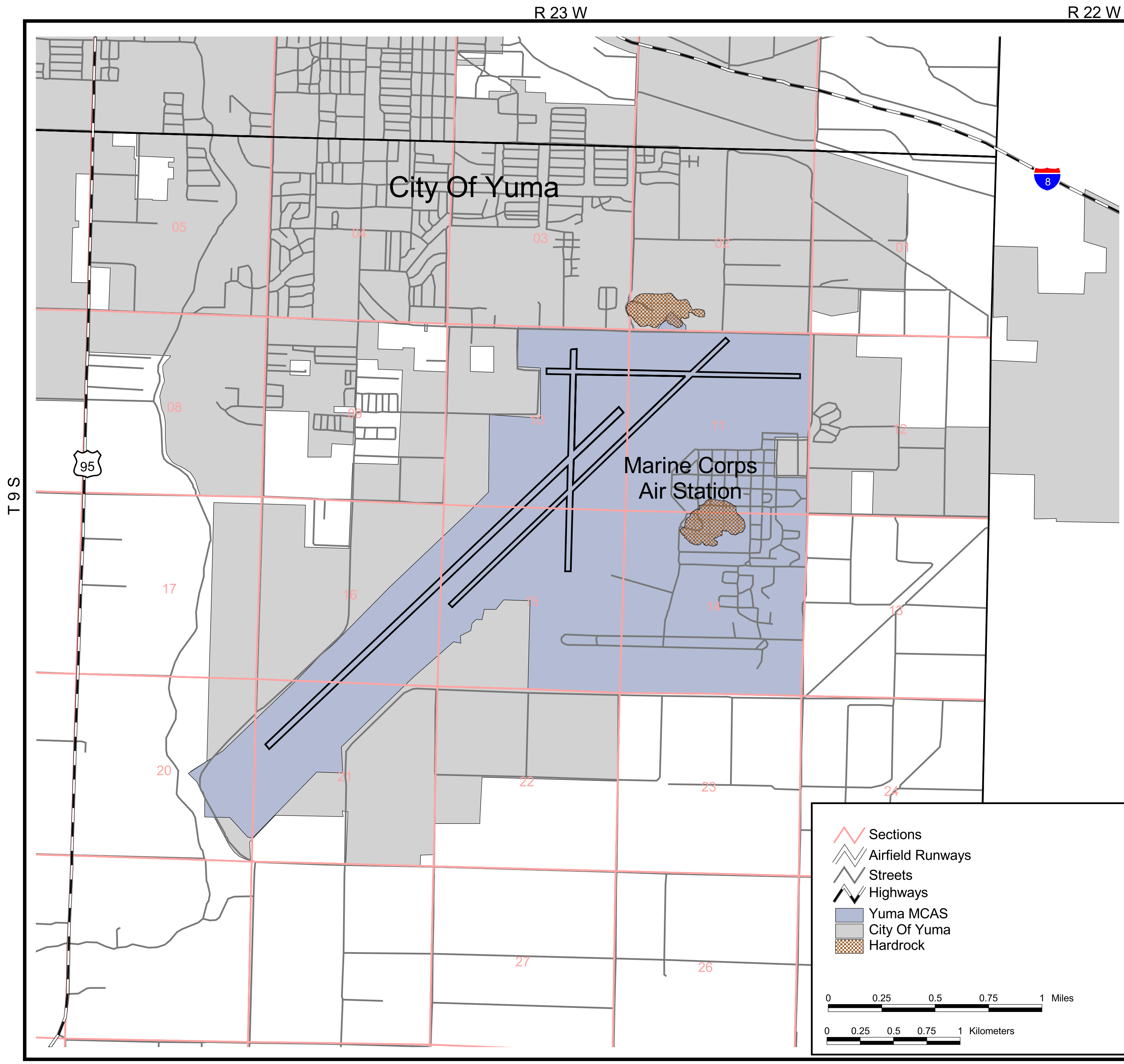
Notes:

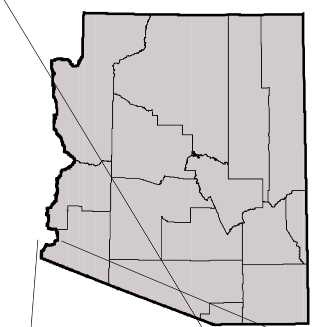
Manufacturer's specifications should be followed to achieve the minimum 25% solids mixtures. Mixing ratios listed in this table are approximate.

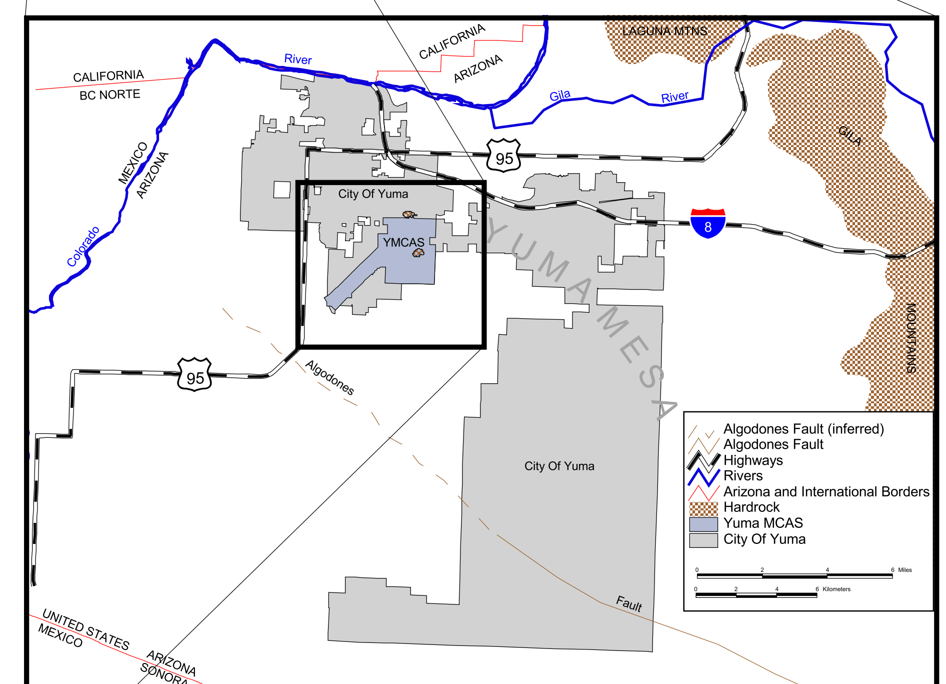
Yuma Marine Corps Air Station

Figure 1

Location Map of the Project Area in the Southeastern Portion of Yuma, Arizona







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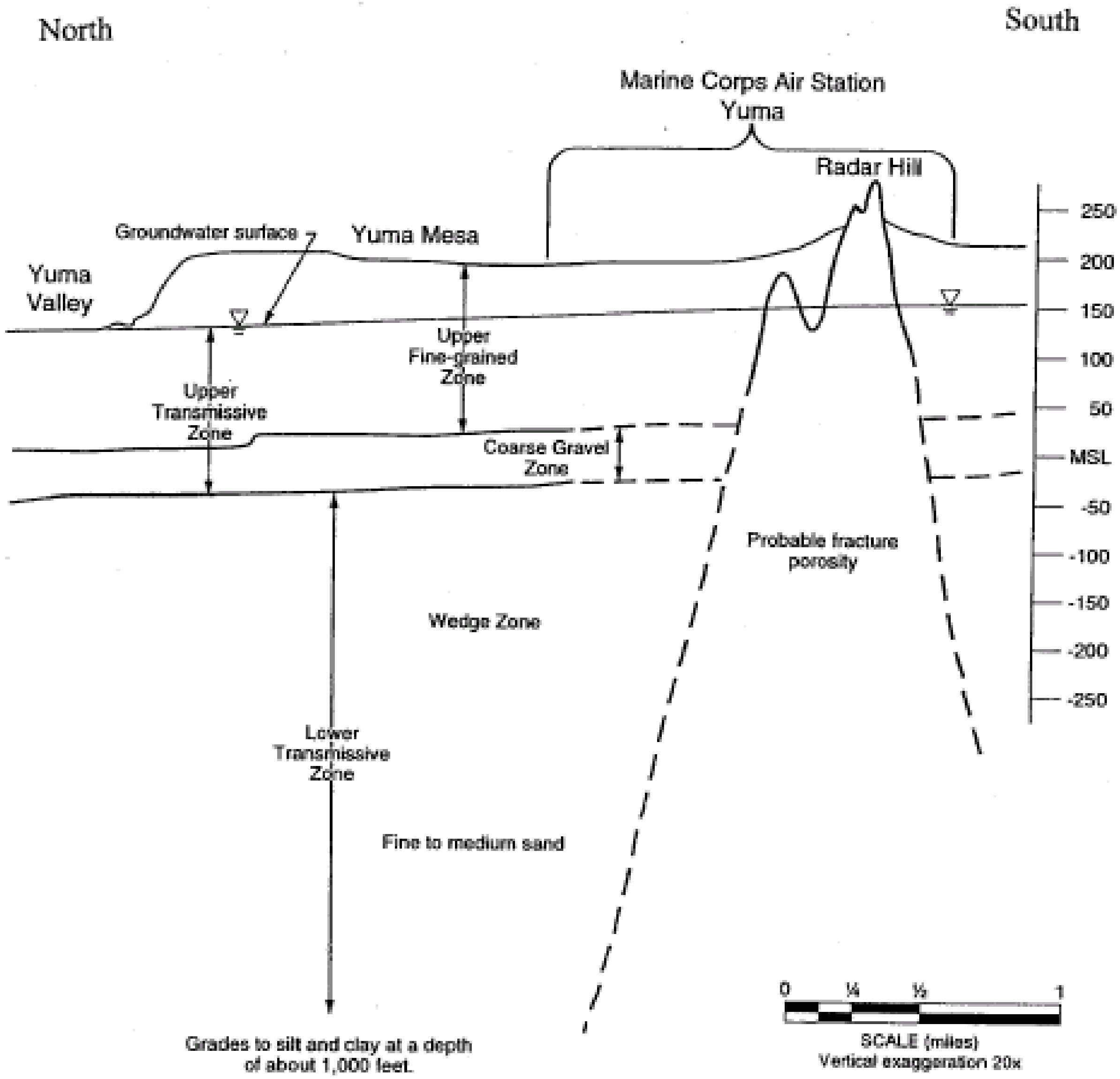
Arizona Department of Water Resources
Hydrology Division, WQARF Unit
Projection: UTM, Zone 12, NAD 27
Produced by:
Date: August 5, 2002
Path: J:\hydro\wqarf\ymcas\arcview\yuma_project.apr\figure 1



[Modified after Olmsted et al, 1973]

Figure 2. Generalized geologic cross-section of Yuma Mesa

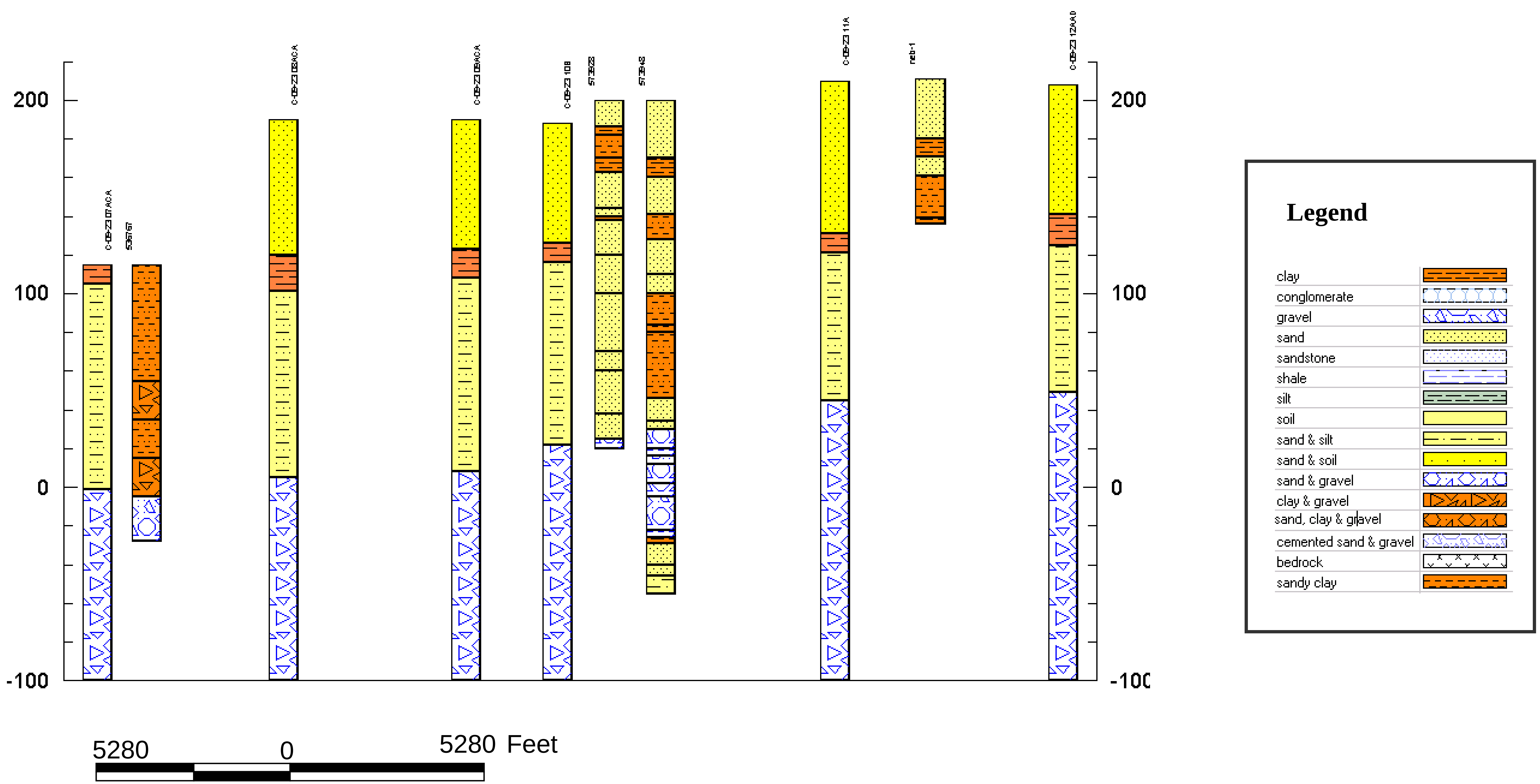
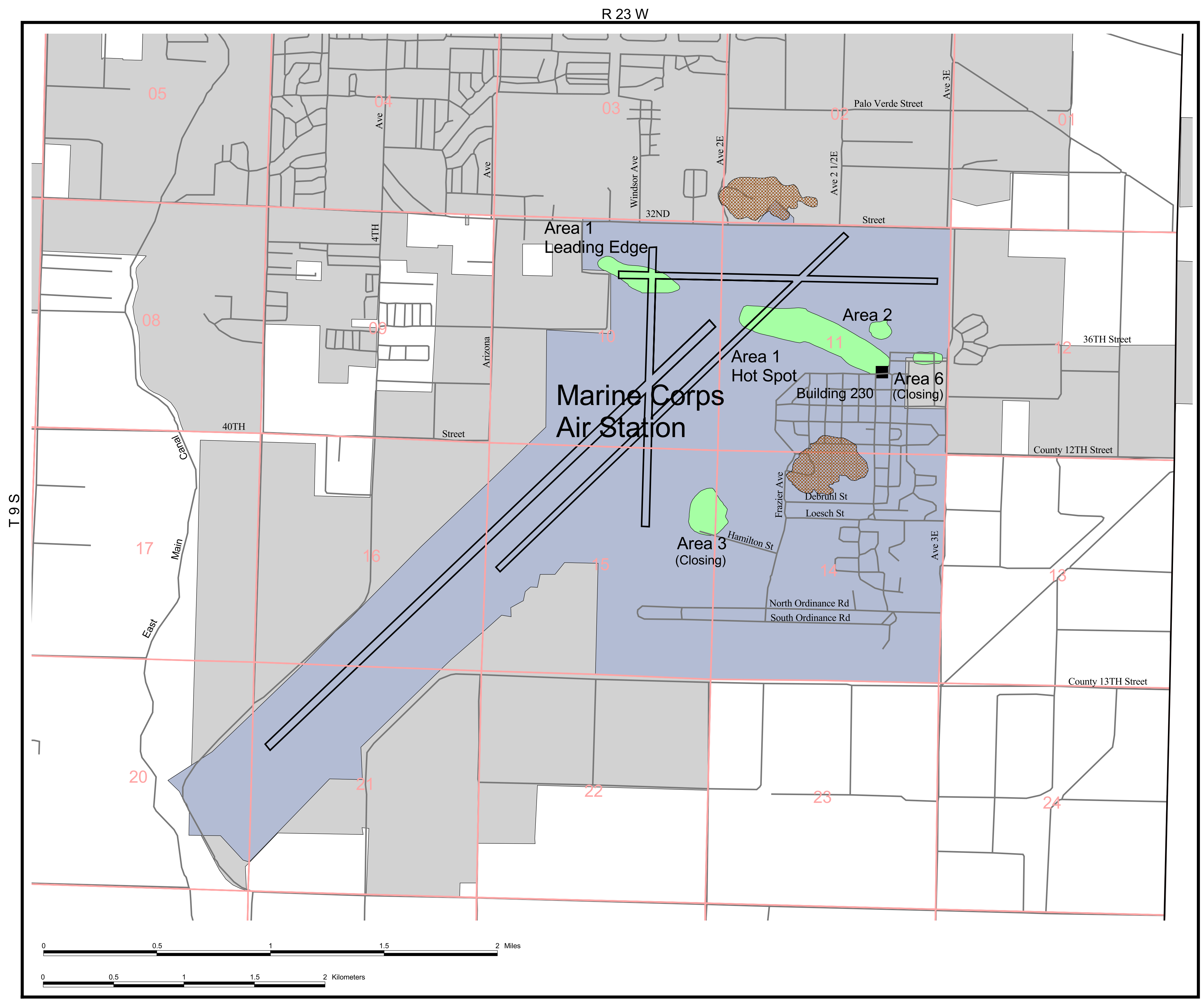


Figure 3. Example of driller and geologist logs and stratigraphy from ADWR modeling report (1993).



Yuma Marine Corps Air Station

Figure 4

Areas of Ground Water Contamination

(as of June, 2001)

Sections
Airfield Runways
Streets
Yuma MCAS
City Of Yuma
Areas of Ground Water Contamination (as of June, 2001)
Hardrock

N

ARIZONA DEPARTMENT OF WATER RESOURCES

Arizona Department of Water Resources
Hydrology Division/WQARF Unit
Projection: UTM, Zone 12, NAD 27
Produced by: Maureen Freark
Date: August 5, 2002
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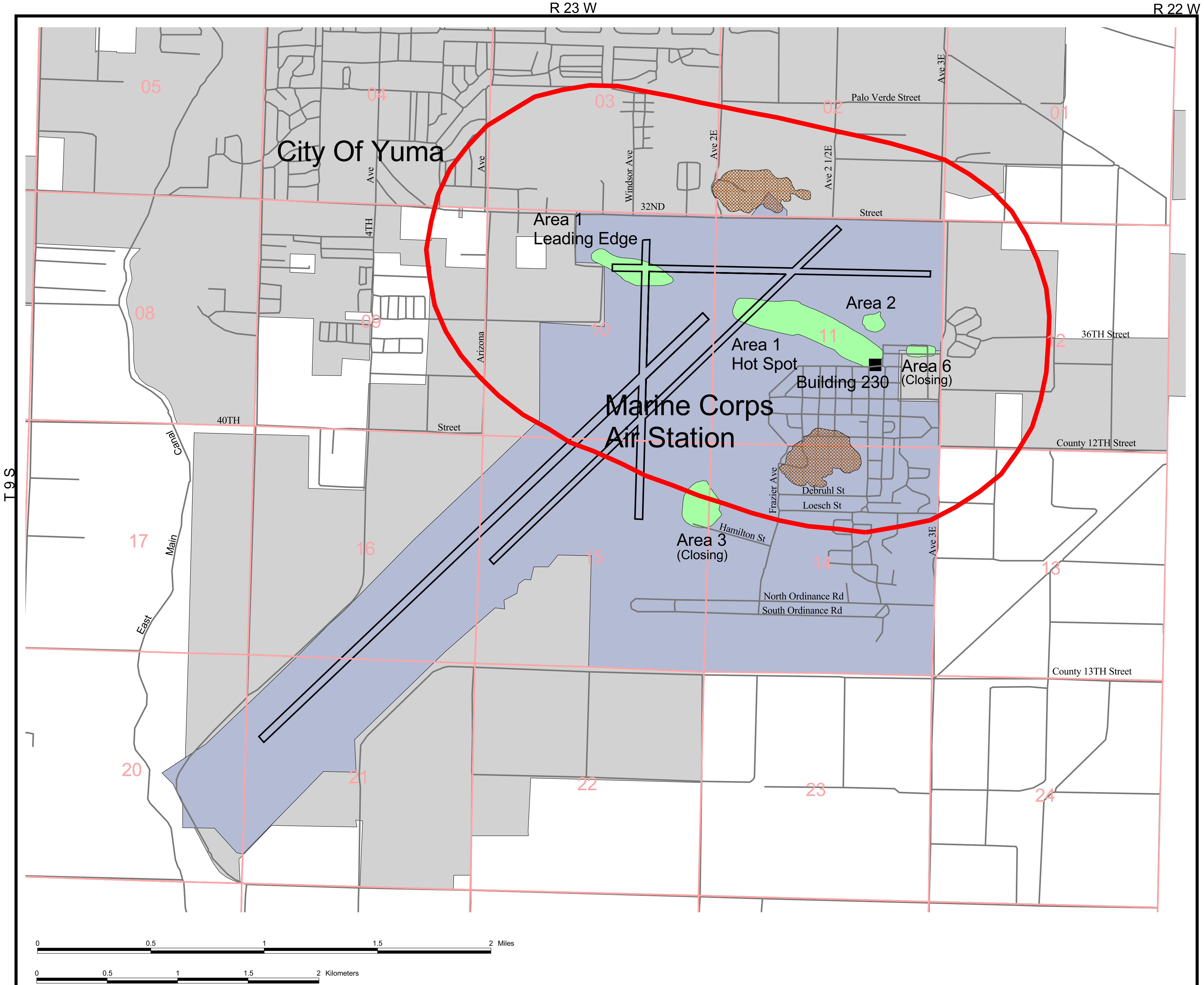
yuma project.apr\figure 4



Yuma Marine Corps Air Station

Figure 5

Area Where Special Well Construction and Abandonment Procedures Apply

- Sections
- Airfield Runways
- Streets
- Area for Special Well Construction & Abandonment Requirements
- Yuma MCAS
- City Of Yuma
- Areas of Ground Water Contamination (as of June, 2001)
- Hardrock

N

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Path: J:\hydro\wqarf\ymcas\arcview\yuma project.apr\figure 5

Typical Acceptable Design for Wells Drilled Within the Yuma Marine Corps Air Station Area Requiring Special Well Construction

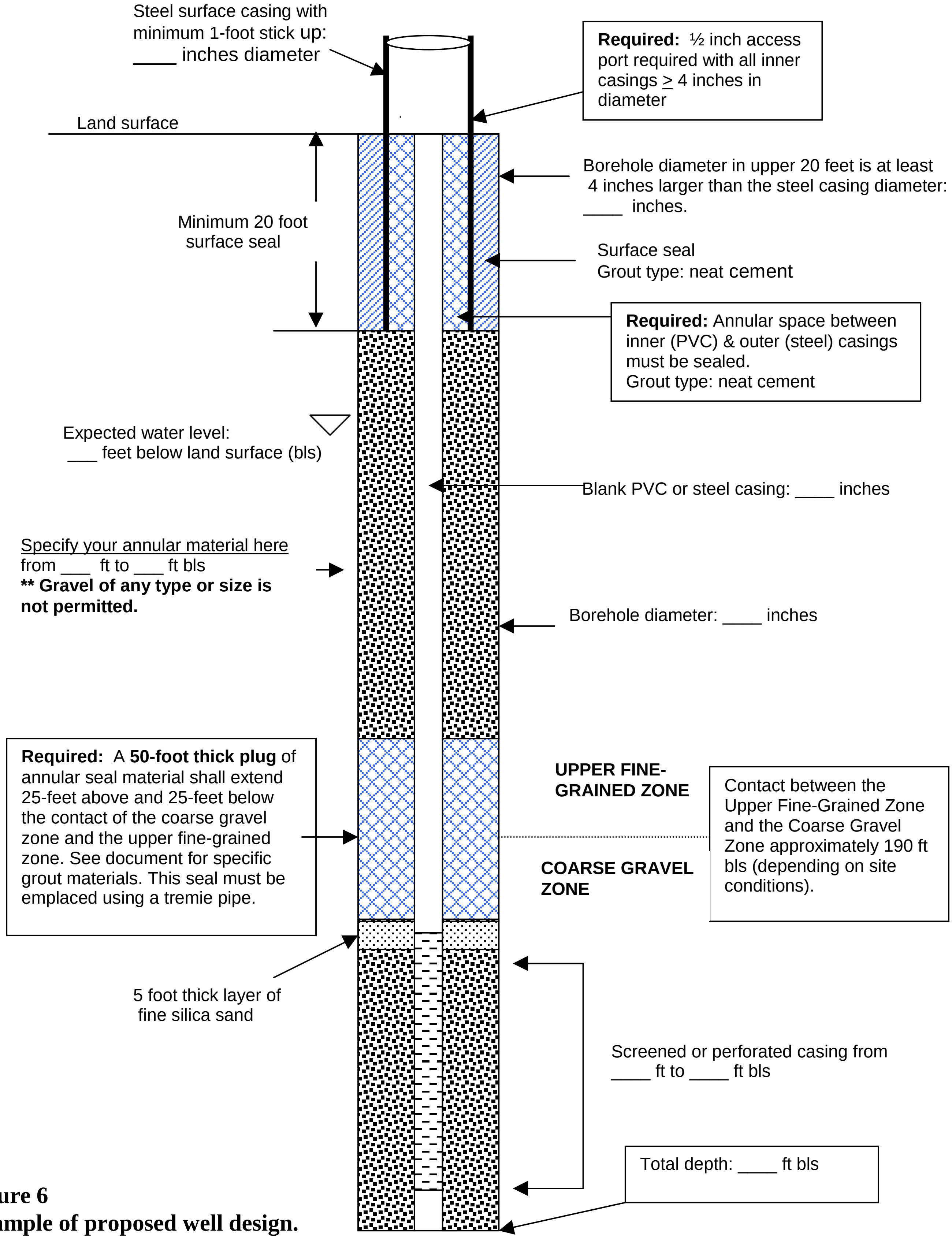

Figure 6
Example of proposed well design.